

## SNOX™ Flue Gas Cleaning Demonstration Project

### Project completed

#### Participant

ABB Environmental Systems

#### Additional Team Members

Ohio Coal Development Office—cofunder

Ohio Edison Company—cofunder and host

Haldor Topsoe a/s—patent owner for process technology, catalysts, and WSA Condenser

Snamprogetti, U.S.A.—cofunder and process designer

#### Location

Niles, Trumbull County, OH (Ohio Edison's Niles Station, Unit No. 2)

#### Technology

Haldor Topsoe's SNOX™ catalytic advanced flue gas cleanup system

#### Plant Capacity/Production

35-MWe equivalent slipstream from a 108-MWe boiler

#### Coal

Ohio bituminous, 2.8% sulfur

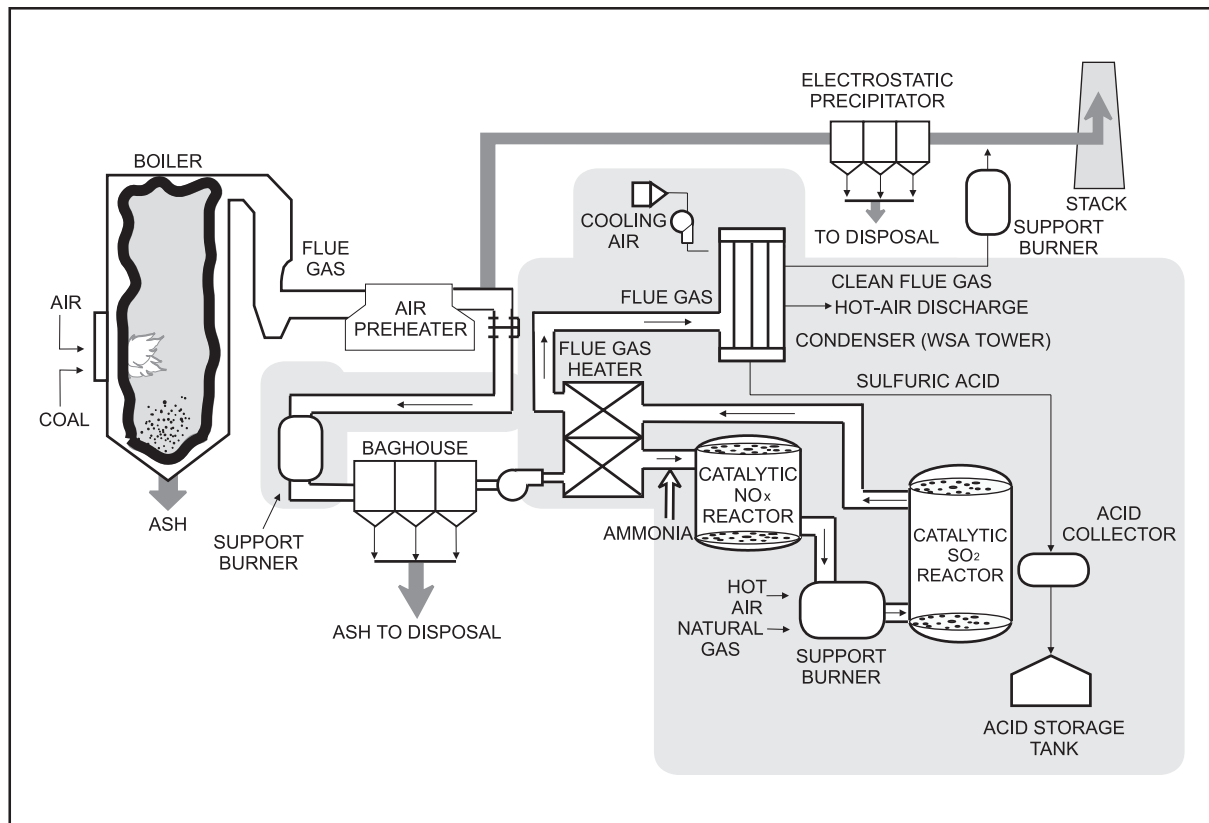
#### Project Funding

|             |              |      |
|-------------|--------------|------|
| Total       | \$31,438,408 | 100% |
| DOE         | 15,719,200   | 50   |
| Participant | 15,719,208   | 50   |

#### Project Objective

To demonstrate SNOX™ technology at an electric power plant using U.S. high-sulfur coals in which it will catalytically remove 95% of SO<sub>2</sub> and more than 90% of NO<sub>x</sub> from flue gas and produce a salable by-product of concentrated sulfuric acid.

SNOX is a trademark of Haldor Topsoe a/s.



#### Technology/Project Description

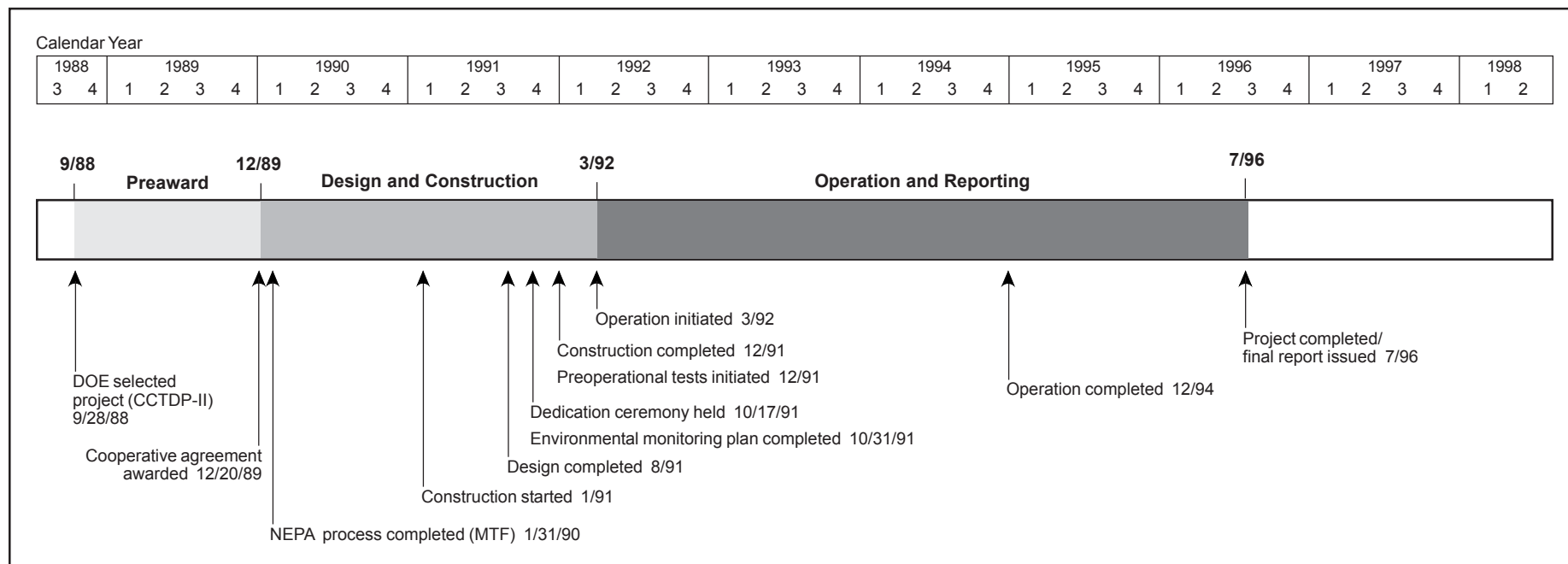
In the SNOX™ process, the stack gas leaving the boiler is cleaned of fly ash in a high-efficiency fabric filter baghouse to minimize the cleaning frequency of the sulfuric acid catalyst in the downstream SO<sub>2</sub> converter. The ash-free gas is reheated, and NO<sub>x</sub> is reacted with small quantities of ammonia in the first of two catalytic reactors where the NO<sub>x</sub> is converted to harmless nitrogen and water vapor. The SO<sub>2</sub> is oxidized to SO<sub>3</sub> in a second catalytic converter. The gas then passes through a novel glass-tube condenser that allows SO<sub>3</sub> to hydrolyze to concentrated sulfuric acid.

Because the SO<sub>2</sub> catalyst follows the NO<sub>x</sub> catalyst, any unreacted ammonia (slip) is oxidized in the SO<sub>2</sub> catalyst largely to nitrogen and water vapor. Downstream fouling by ammonia compounds is eliminated, permitting opera-

tion at higher than normal stoichiometries. These higher stoichiometries allow smaller catalyst volumes and high reduction efficiencies.

The technology was designed to remove 95% of the SO<sub>2</sub> and more than 90% of the NO<sub>x</sub> from flue gas, and produce a salable sulfuric acid by-product using U.S. coals. This was accomplished without using sorbents and without creating waste streams.

The demonstration was conducted at Ohio Edison's Niles Station in Niles, Ohio. The demonstration unit treated a 35-MWe equivalent slipstream of flue gas from the 108-MWe Unit No. 2 boiler, which burned a 2.8% sulfur Ohio coal. The process steps were virtually the same as for a full-scale commercial plant, and commercial-scale components were installed and operated.



## Results Summary

### Environmental

- SO<sub>2</sub> removal efficiency was normally in excess of 95% for inlet concentrations, averaging about 2,000 ppm.
- NO<sub>x</sub> reduction averaged 94% for inlet concentrations ranging from 500–700 ppm.
- Particulate removal efficiency for the high-efficiency fabric filter baghouse with SNOX™ system was greater than 99%.
- Sulfuric acid purity exceeded federal specifications for Class I acid.
- Air toxics testing showed high capture efficiency of most trace elements in the baghouse. A significant portion of the boron and almost all of the mercury escaped to the stack; but selenium and cadmium, normally a problem, were effectively captured in the acid drain, as were organic compounds.
- Absence of an alkali reagent contributed to elimination of secondary pollution streams and no increases in CO<sub>2</sub> emissions.

- Presence of the SO<sub>2</sub> catalyst virtually eliminated CO and hydrocarbon emissions.

### Operational

- Having the SO<sub>2</sub> catalyst downstream of the NO<sub>x</sub> catalyst eliminated ammonia slip and allowed the SCR to function more efficiently.
- Heat developed in the SNOX™ process was used to enhance thermal efficiency.

### Economic

- Capital cost was estimated at \$305/kW for a 500-MWe unit firing 3.2% sulfur coal. The 15-year levelized incremental cost was estimated at 6.1 mills/kWh, \$219/ton of SO<sub>2</sub> removed, and \$198/ton of SO<sub>2</sub> and NO<sub>x</sub> removed on a constant 1995 dollar basis.

## Project Summary

No reagent was required for the  $\text{SO}_2$  removal step because the SNOX™ process utilized an oxidation catalyst to convert  $\text{SO}_2$  to  $\text{SO}_3$  and ultimately to sulfuric acid. As a result, the process produced no waste streams.

In order to demonstrate and evaluate the performance of the SNOX™ process, general operating data were collected and parametric tests conducted to characterize the process and equipment. The system operated for approximately 8,000 hours and produced more than 5,600 tons of commercial-grade sulfuric acid. Many of the tests for the SNOX™ system were conducted at three loads—75, 100, and 110% of design capacity.

### Environmental Performance

Particulate emissions from the process were very low ( $<1 \text{ mg/Nm}^3$ ) due to the characteristics of the  $\text{SO}_2$  catalyst and the sulfuric acid condenser (WSA Condenser). The Niles SNOX™ plant was fitted with a baghouse (rather than an ESP) on its inlet. This was not necessary for low particulate emissions, but rather was needed to maintain an acceptable cleaning frequency for the  $\text{SO}_2$  catalyst. At operating temperature, the  $\text{SO}_2$  catalyst retained about 90% of the dust that entered the catalyst vessel because of its sticky surface. Dust that passed through was subsequently removed in the WSA Condenser, which acted as a condensing particulate removal device (utilizing the dust particulates as nuclei).

Minimal or no increase in  $\text{CO}_2$  emissions by the process resulted from two features—the lack of a carbonate-based alkali reagent that releases  $\text{CO}_2$ , and the fact that the process recovered additional heat from the flue gas to offset its parasitic energy requirements. Under most design conditions this heat recovery results in the net heat rate of the boiler remaining the same or decreasing after addition of the SNOX™ process, and consequently no increase occurs in  $\text{CO}_2$  generation.

With respect to CO and hydrocarbons, the  $\text{SO}_2$  catalyst acted to virtually eliminate these compounds as well. This aspect also positively affected the interaction of the  $\text{NO}_x$  and  $\text{SO}_2$  catalysts. Because the  $\text{SO}_2$  catalyst followed the  $\text{NO}_x$  catalyst, any unreacted ammonia (slip) was oxidized in the  $\text{SO}_2$  catalyst to nitrogen, water vapor,

and a small amount of  $\text{NO}_x$ . As a result, downstream fouling by ammonia compounds was eliminated, and the SCR was operated at slightly higher than typical ammonia stoichiometries. These higher stoichiometries allowed smaller SCR catalyst volumes and permitted the attainment of very high reduction efficiencies. Normal operating stoichiometries for the SCR system were in the range of 1.02–1.05, and system reduction efficiencies averaged 94% with inlet  $\text{NO}_x$  levels of approximately 500–700 ppm.

Sulfur dioxide removal in the SNOX™ process was controlled by the efficiency of the  $\text{SO}_2$ -to- $\text{SO}_3$  oxidation, which occurred as the flue gas passed through the oxidation catalyst beds. The efficiency was controlled by two factors—space velocity and bed temperature. Space velocity governed the amount of catalyst necessary at design flue gas flow conditions, and gas and bed temperature had to be high enough to activate the  $\text{SO}_2$  oxidation reaction. During the test program,  $\text{SO}_2$  removal efficiency was normally in excess of 95% for inlet concentrations averaging about 2,000 ppm.

Sulfuric acid concentration and composition have met or exceeded the requirements of the federal specifications for Class I acid. During the design and construction of the SNOX™ demonstration, arrangements were made with a sulfuric acid supplier to purchase and distribute the acid from the plant. The acid has been sold to the agriculture industry for production of diammonium phosphate fertilizer and to the steel industry for pickling. Ohio Edison also has used a significant amount in boiler water demineralizer systems throughout its plants.

Air toxics testing conducted at the Niles SNOX™ plant measured the following substances:

- Five major and 16 trace elements including mercury, chromium, cadmium, lead, selenium, arsenic, beryllium, and nickel;
- Acids and corresponding anions (hydrogen chloride, hydrogen fluoride, chloride, fluoride, phosphate, sulfate);
- Ammonia and cyanide;
- Elemental carbon;
- Radionuclides;



The bottom portion of the  $\text{SO}_2$  converter reactor, with the catalyst dust collector hopper mounted on steel rails (center).

- Volatile organic compounds;
- Semi-volatile compounds, including polynuclear aromatic hydrocarbons; and
- Aldehydes.

Most trace elements were captured in the baghouse along with the particulates. A significant portion of the boron and almost all of the mercury escaped to the stack; but selenium and cadmium, normally a problem, were effectively captured in the acid drain, as were organic compounds.

## Operational Performance

Heat recovery was accomplished by the SNOX™ process. In a commercial configuration, it can be utilized in the thermal cycle of the boiler. The process generated recoverable heat in several ways. All of the reactions that took place with respect to NO<sub>x</sub> and SO<sub>2</sub> removal were exothermic and increased the temperature of the flue gas. This heat, plus fuel-fired support heat added in the high-temperature SCR/SO<sub>2</sub> catalyst loop, was recovered in the WSA Condenser cooling air discharge for use in the furnace as combustion air. Because the WSA Condenser lowered the temperature of the flue gas to about 210 °F, compared with approximately 300 °F for a typical power plant, additional thermal energy was recovered along with that from the heats of reaction.

## Economic Performance

The economic evaluation of the SNOX™ process showed a capital cost of approximately \$305/kW for a 500-MWe unit firing 3.2% sulfur coal. The 15-year levelized incremental cost was 6.1 mills/kWh on a constant dollar basis (1995\$). The equivalent costs of pollutant removed were \$219/ton of SO<sub>2</sub>, and \$198/ton of SO<sub>2</sub> and NO<sub>x</sub>.

## Commercial Applications

The SNOX™ technology is applicable to all electric power plants and industrial/institutional boilers firing coal, oil, or gas. The high removal efficiency for NO<sub>x</sub> and SO<sub>2</sub> makes the process attractive in many applications. Since the SNOX™ technology produces no solid waste, its marketability is enhanced in urban and other areas where solid waste disposal is a significant problem.

The host utility, Ohio Edison, is retaining the SNOX™ technology as a permanent part of the pollution control system at Niles Station to help Ohio Edison meet its overall SO<sub>2</sub>/NO<sub>x</sub> reduction goals.

Commercial SNOX™ plants also are operating in Denmark and Sicily. In Denmark, a 305-MWe plant has operated since August 1991. The boiler at this plant burns coals from various suppliers around the world, including the United States; the coals contain 0.5–3.0% sulfur. The plant in Sicily, operating since March 1991, has a capacity of about 30 MWe and fires petroleum coke.

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*A Study of Toxic Emissions from a Coal-Fired Power Plant Utilizing the SNOX™ Innovative Clean Coal Technology Demonstration. Volume 2, Appendices: Final Report.* Report No. DOE/PC/93251-T3-Vol. 2. Battelle Columbus Operations. July 1994. (Available from NTIS as DE94018833.)

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The SNOX™ demonstration at Ohio Edison's Niles Station Unit No. 2 achieved SO<sub>2</sub> removal efficiencies exceeding 95% and NO<sub>x</sub> reduction effectiveness averaging 94%. Ohio Edison is retaining the SNOX™ technology as part of its environmental control system.